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LCA of electricity systems with high wind power penetration

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Electricity systems are shifting from being based on fossil fuels towards renewable sources to enhance energy security and mitigate climate change. However, by introducing high shares of variable renewables - such as wind and solar - dispatchable power plants are required to vary their output to fulfill the remaining electrical demand, potentially increasing their environmental impacts [1,2]. In this study the environmental impacts of potential short-term future electricity systems in Ireland with high shares of wind power (35-50% of total installed capacity) were evaluated using life cycle assessment (LCA). Cycling emissions from dispatchable generators due to part-load operation and start-ups [3] were included for the first time in LCA.

Part-load operations significantly affected the average power plant efficiency, with all units seeing an average yearly efficiency 1-11% lower than optimal. Given that similar penalties were seen for power plant with the same role in the system (i.e. load following, mid merit, and base load), it is suggested that only power plants within the same category should be compared. Since power production technologies are typically modeled in LCA assuming steady-state operation at full load [4], the efficiency reduction would result in a large underestimation of emissions, especially for load following power plants.

With regards to the entire electricity system, cycling emissions accounted for less than 10% of lifecycle CO_2, NO_x and SO_2 emissions in the scenarios considered: while not outweighing the benefits from increasing wind energy, cycling emissions are not negligible and should thus be systematically included (i.e. by using emission factors per unit of fuel input rather than per unit of power generated). Cycling emissions increased with the installed wind capacity, and decreased with the addition of storage. However, a consequence of adding storage was the increased use of base load coal power plants, ultimately leading to an increase in total emissions from the Irish electricity system. Consequently, the present study indicates that while investing in new storage capacity reduces system operating costs at high wind penetrations and limits cycling, the emissions reductions may be negated when coupled with base load coal.

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